DOE Fossil Energy Hybrid Research

Third Annual DOE / U.N. Hybrid Conference and Workshop

May 13 – 15, 2003

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www.netl.doe.gov

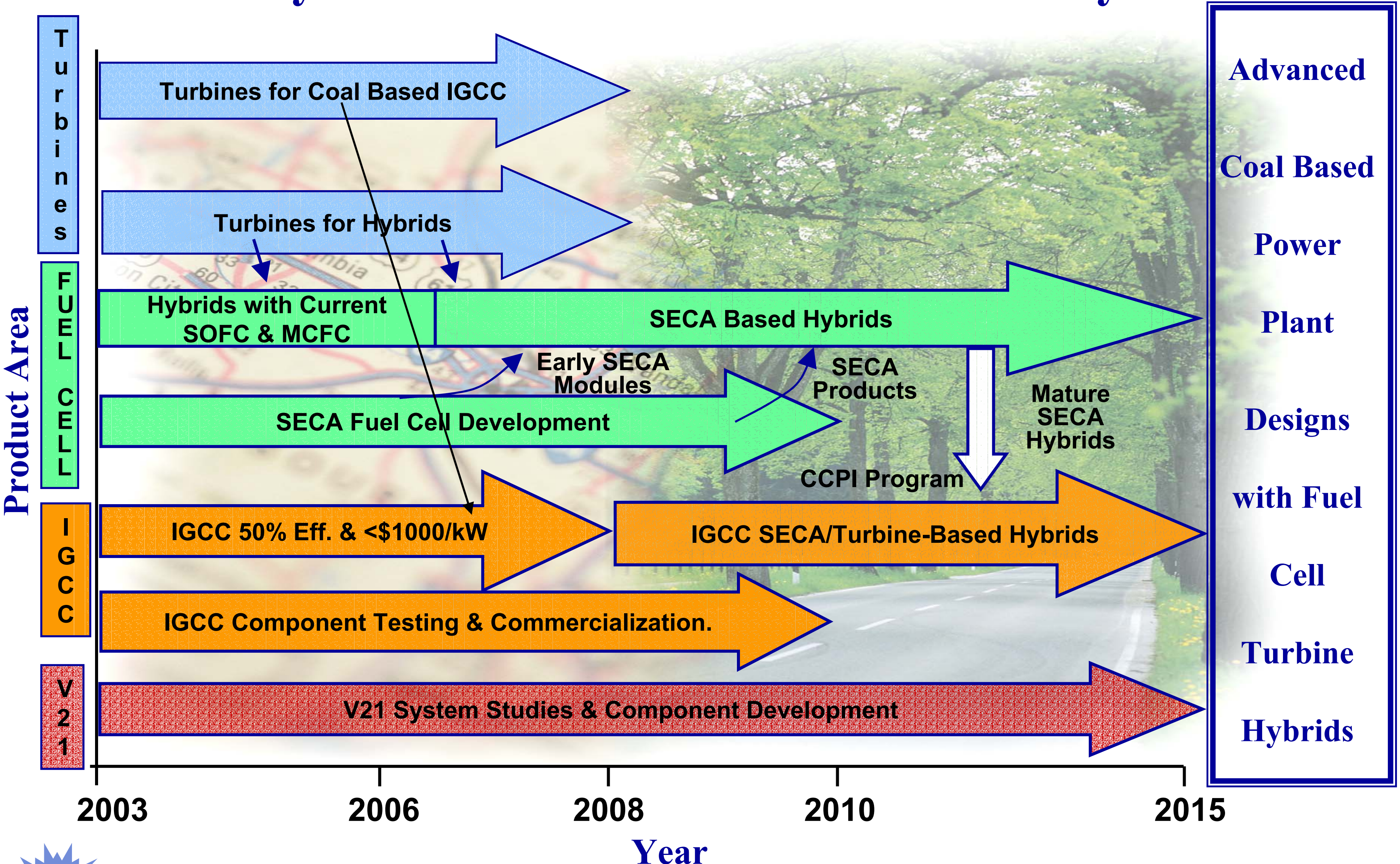
Presentation Outline

- Why Fuel Cell Turbine hybrids ?
- Technical issues for Fuel Cell Turbine Hybrids
- DOE FE NETL Hybrid Related Projects
- Conclusions

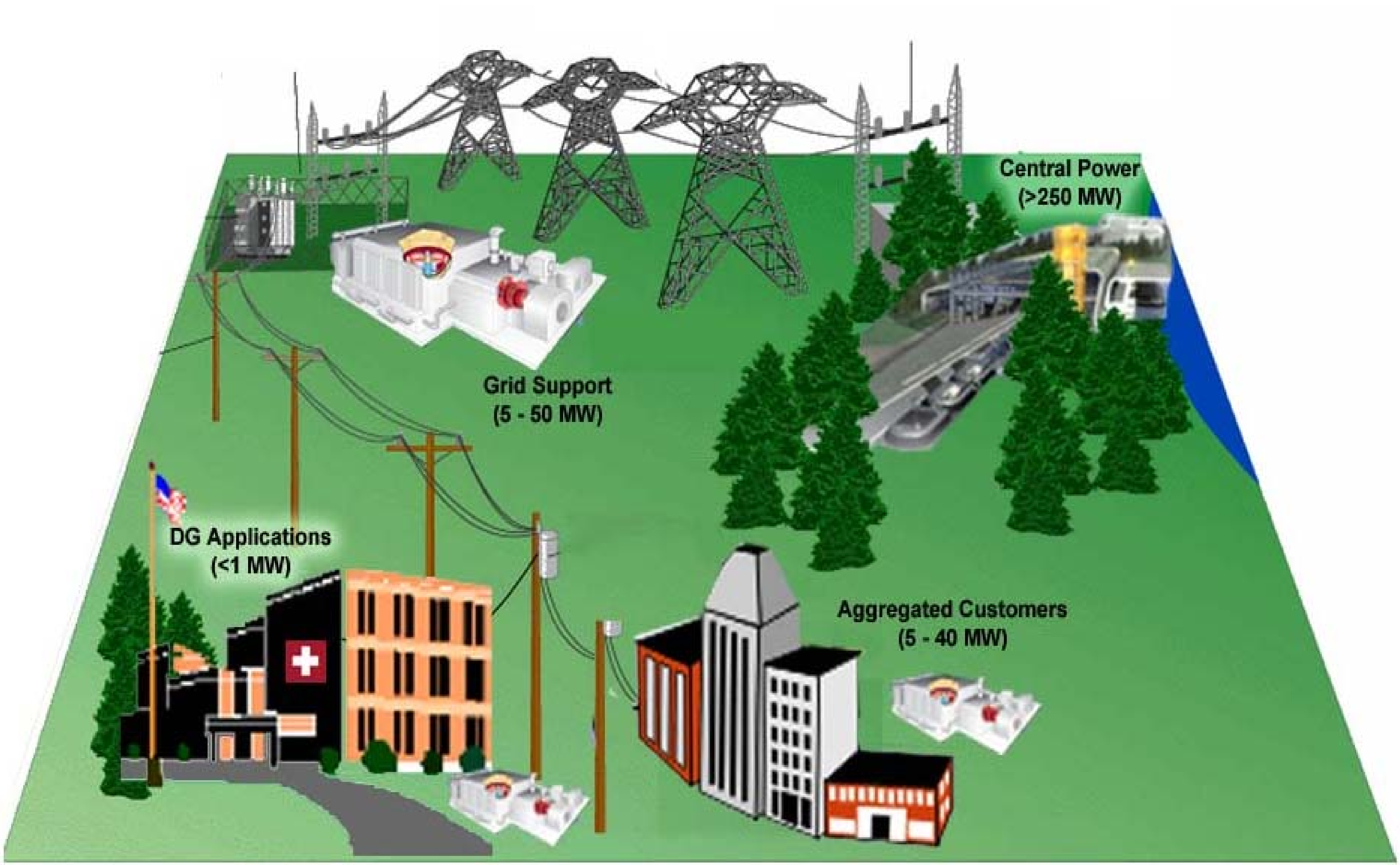
DOE Fossil Energy Hybrid Research

Why Fuel Cell Turbine hybrids ?

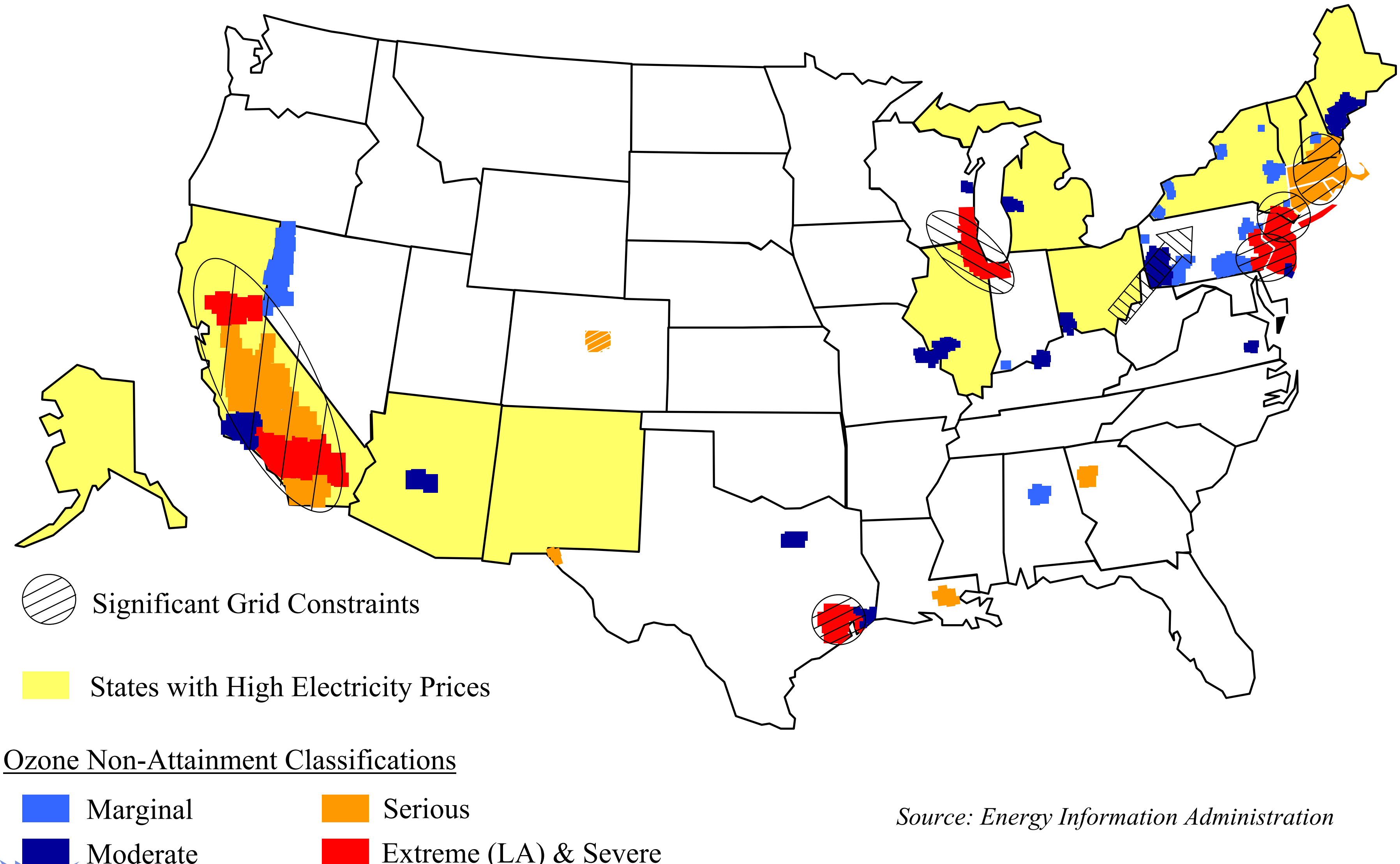
Pathways to Advanced Coal Based Power Systems



Hybrids have Multiple Applications

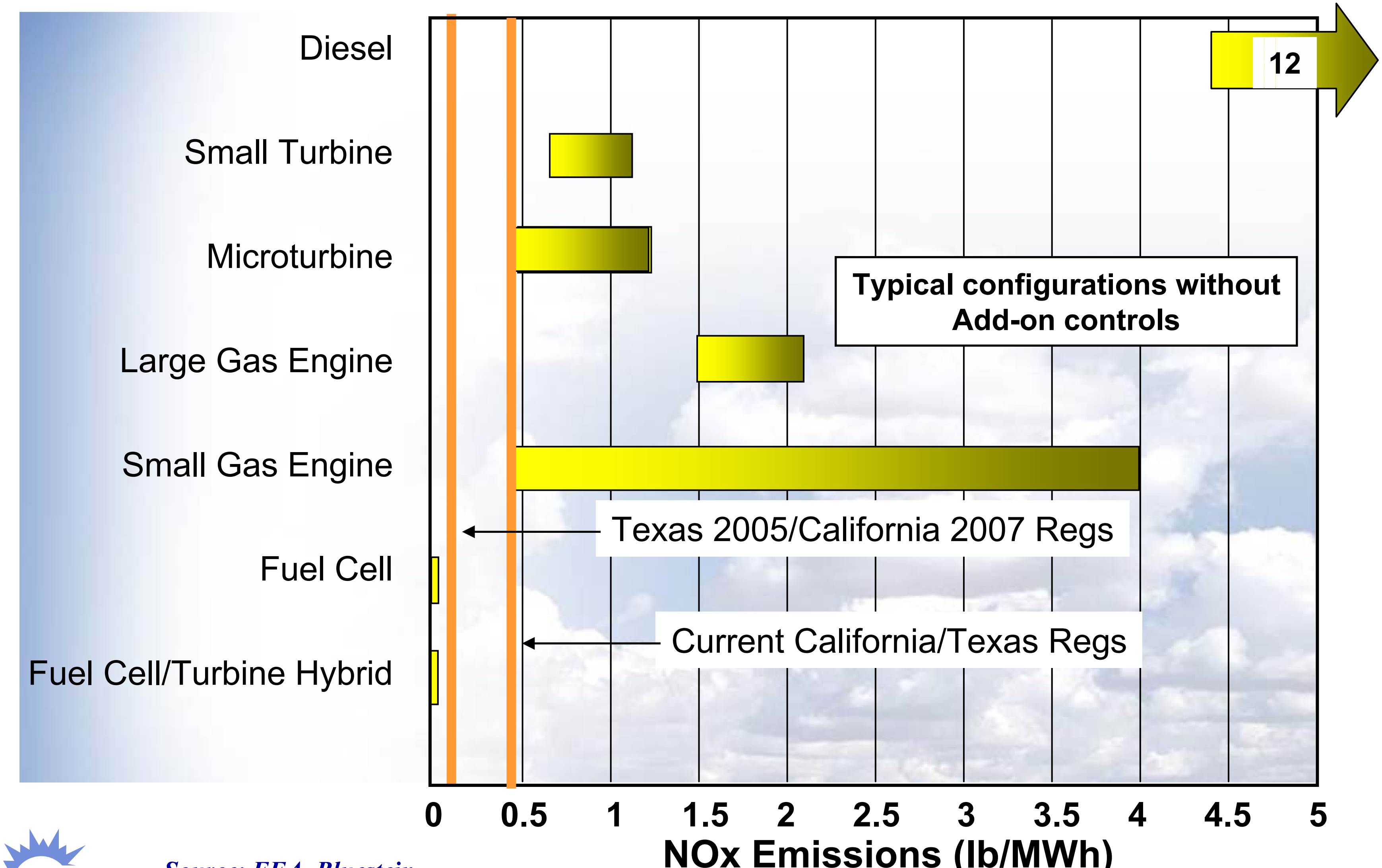


Convergence of Volatility and Uncertainty



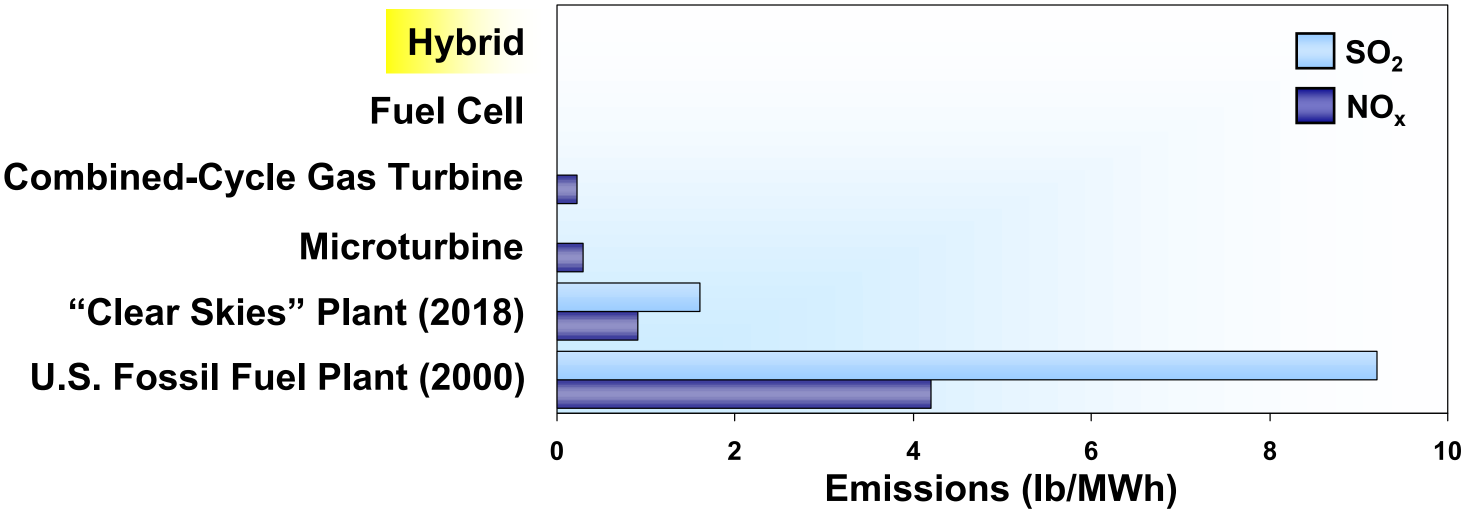
Source: Energy Information Administration

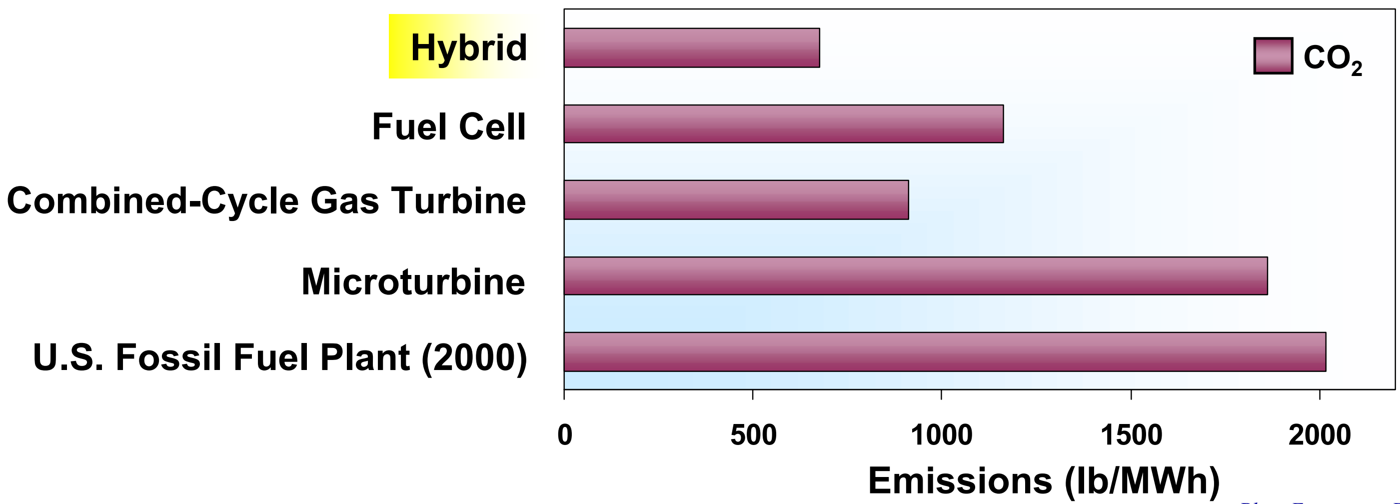
Many DG Systems Cannot Meet The New Regs



Source: EEA, Bluestein

Hybrid Efficiency Leads to Low Emissions





Plant Estimates: D. Smith, NETL
Hybrid Estimates: L. Berkshire, NETL
Other Technology Estimates: S. O'Brien, UTC Fuel Cells

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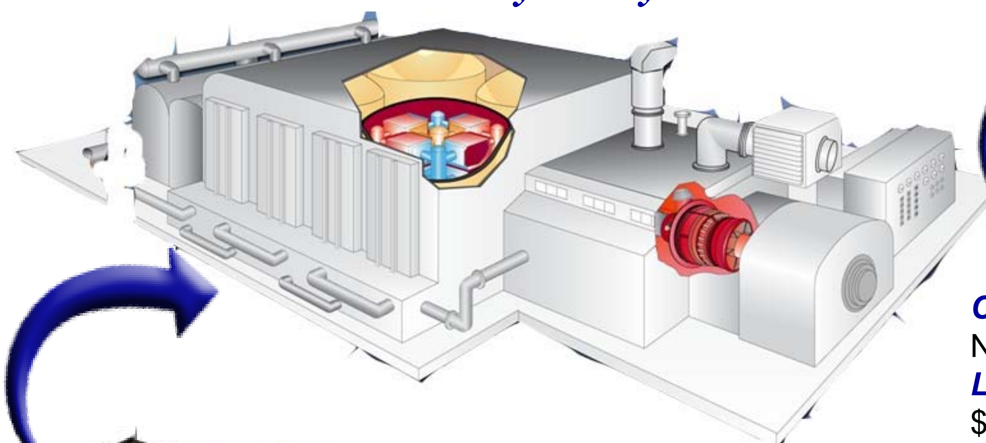
Potential Advantages to Distributed Generation

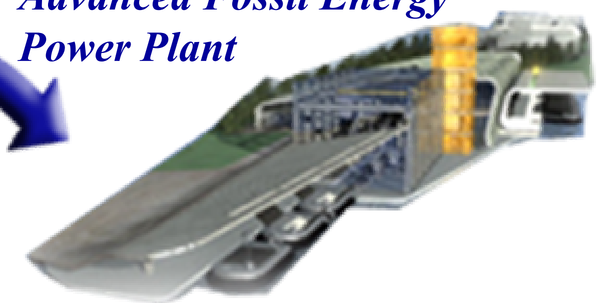
- Reduced Demand & Energy Costs
- Deferred T&D Upgrades
- Reduced System Losses
- Voltage Support
- Increased Reliability, Quality, & Efficiency
- Greater Use of Assets
- Reduced Emissions with New Technologies
- Ideal for remote locations with no grid infrastructure or areas with capacity constrained grid
- Diversity and fuel flexibility enhance energy security

Fuel Cell Turbine Hybrids are Required for DOE's FE Advanced Power Plants

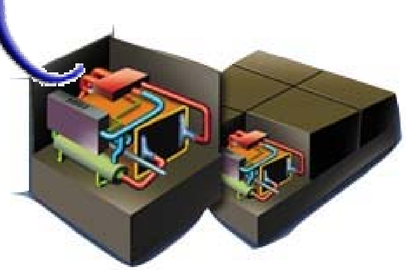
Hybrid System



Advanced Fossil Energy Power Plant



Clean
Near-zero Emissions
Low Cost
$400 per kilowatt
Flexible
Multiple fuel capacity
Energy Security
Rely on our vast domestic supply of coal



Solid Oxide Fuel Cells

Turbines

Office of Fossil Energy

Turbine Program

Gasification Technologies Program

Fuel Cell Program

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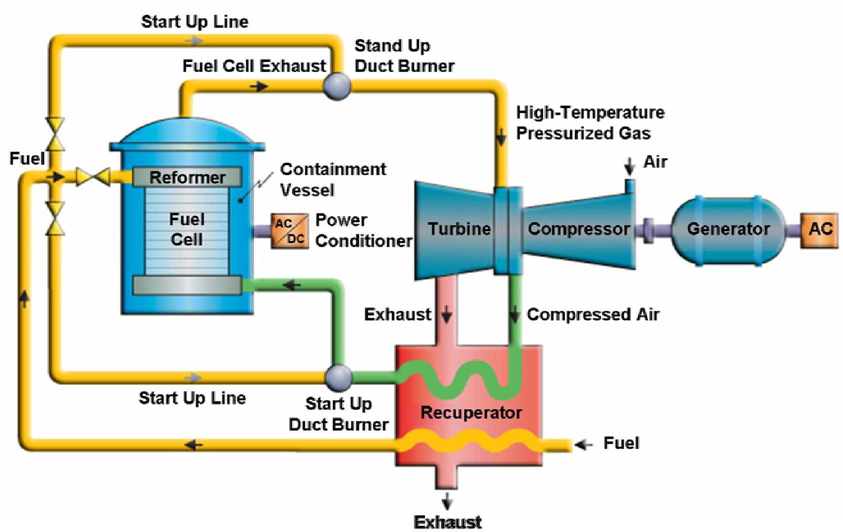
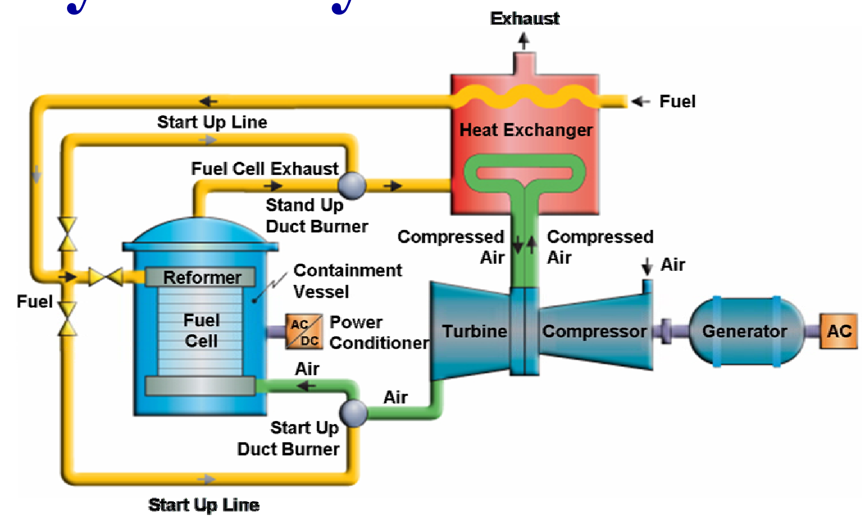
Technical issues for Fuel Cell Turbine Hybrids

Fuel Cell Turbine Hybrid Cycles





Direct Cycle	Characteristic	Indirect Cycle
Pressurized	Fuel Cell Pressure	Non-Pressurized
Higher	Efficiency	High
More Difficult to Match	Flow & Pressure/ratio	Easier to Match
Limited	Operational Flexibility	Some

Workshop Results
2nd Conference on Hybrid Power Systems (April, 2002)

Technical Issues

- **Need process for design of optimal system, not suboptimal integration of optimal components (♦ ♦ ♦ ♦ ♦ ♦ ♦)**
- **What architecture / topography leads to the least expensive stack/system (♦ ♦ ♦ ♦ ♦ ♦ ♦)**
- **Turbine integration issues (♦ ♦ ♦ ♦ ♦ ♦)**
  - Avoid sudden depressurization
  - Large volume of high pressure gas–pressure vessel codes–turbines do not meet the code
  - Avoid reverse flows, i.e., hot gas through compressor
- **Combine fuel cell with non-turbine engines (i.e., RAMGEN engine), DOE HEET (♦ ♦ ♦ ♦ ♦)**
- **Hybrids need purpose-designed micro turbine gensets (♦ ♦ ♦ ♦)**

Workshop Results

2nd Conference on Hybrid Power Systems (April, 2002)

Market Issues

- What is the distributed generation market potential? How does that compare to the Central Generation market potential? R&D efforts should be focused on most valuable market (♦ ♦ ♦ ♦)
- Cost is not the only issue for residential market-convenience and reliability rule (♦ ♦ ♦ ♦)
- DOE and industry should seek tax credits for DG, hybrids, “Green Power” fuel cell production (♦ ♦ ♦ ♦)

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Technical Issues for Hybrids

- **DG hybrid systems, natural gas fueled (0.5 – 50 MW)**
  - Turbine: Increase turbine surge margin, enhanced performance with lower quality thermal input and lower pressure ratios.
  - Combustors: Combustors with high turn down ratios (0 - 100 %), relight capability, high heat flux tolerant combustors without cooling, enhanced performance with lower quality thermal input.

- **Central hybrid systems, coal & natural gas fueled (> 100 MW)**
  - Many of the above from DG hybrids
  - Higher pressure systems
  - Unique cycles (humid air turbine, etc.)
  - Turbines with higher pressure ratios (30 – 50), higher turbine inlet temp (~3,000 F) and intercoolers

DOE FE NETL Hybrid Related Projects

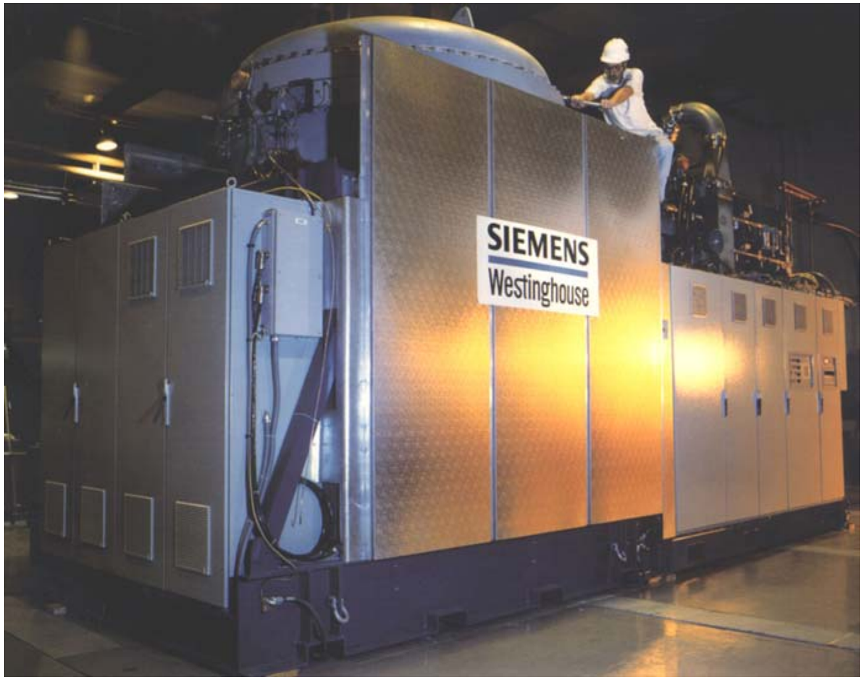
- Fuel Cell Energy – Critical Components for Direct Fuel Cell/Turbine Ultra-Efficiency System (40798)
- Siemens Westinghouse – High-Temperature Tubular Solid Oxide Fuel Cell Generation Development (34139)
- University of California, Irvine – Systems Integration Methodology (40845)
- GE - SOFC Hybrid System for Distributed Power Generation (40779)
- Hybrid Performance Project (NETL In-House)
- Solid State Energy Conversion Alliance (SECA)
- TIAX – Scale-Up of Planar SOFC for MW-Scale Systems (through P3EA support contract)

Fuel Cell Energy – Critical Components for Direct Fuel Cell/Turbine Ultra-Efficiency System

- **Objective: Design a 40 MW FC/T hybrid based on carbonate FC technology with sub-MW prototype demonstrations**
- 280 kW (nominal) system completed 6,740 hrs. of testing
  - Efficiency of 52%
  - NOx & SOx below 0.1 ppm
- Fully integrated hybrid system to be designed with 60 kW capstone engine for a demo in Montana
  - Investigate suitable gas turbine and recuperator technologies for DFC/T systems
- 40 MW power plant design
  - Steady state simulation program has been initiated.
  - Parametric studies with regard to the effects of gas turbine compression ratio on power plant efficiency have been initiate

Siemens Westinghouse – High-Temperature Tubular Solid Oxide Fuel Cell Generation Development

- **Objectives: Demonstrate the technical feasibility and high efficiency (45 – 60 %) of SOFC hybrids**
- The world's first SOFC Hybrid
  - 3000 hrs. of operation
  - Pressurized operation
  - 53 % efficiency
- Future Plans
  - Concentrate on commercialization of an atmospheric pressure CHP250 standard product
  - Seek optimize gas turbine & SOFC stack and configuration for production at the end of this decade.

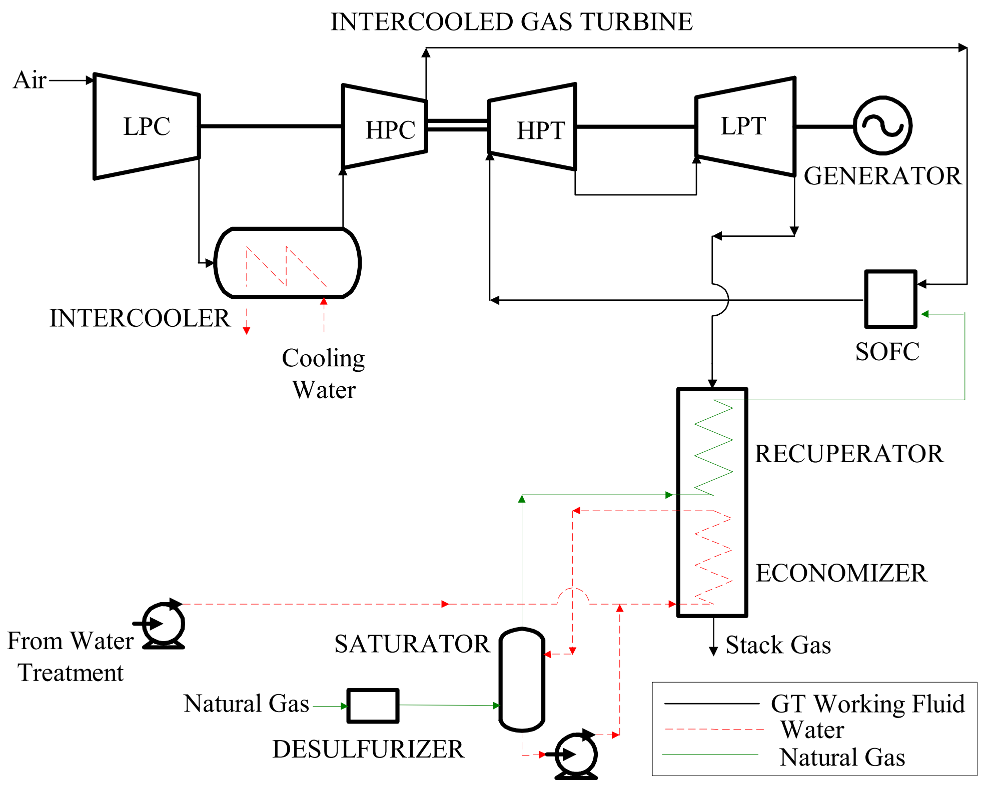


University of California, Irvine – Systems Integration Methodology

- **Objective: Identify coal- and natural- gas-based systems to meet V21 goals with options for carbon sequestration**
- Gas turbine / fuel cell hybrids are required to attain V21 efficiency goals
- Dynamic performance under full- and part-load conditions for down selected systems

NG: HIGH PRESSURE IC GT/SOFC

Eff. $_{LHV}$ > 75%, PR ≅ 50



GE - SOFC Hybrid System for Distributed Power Generation

Objective: *Demonstrate proof-of-concept SOFC for DG*

<u>Phase 1</u> (Q1/03 – Q4/03)

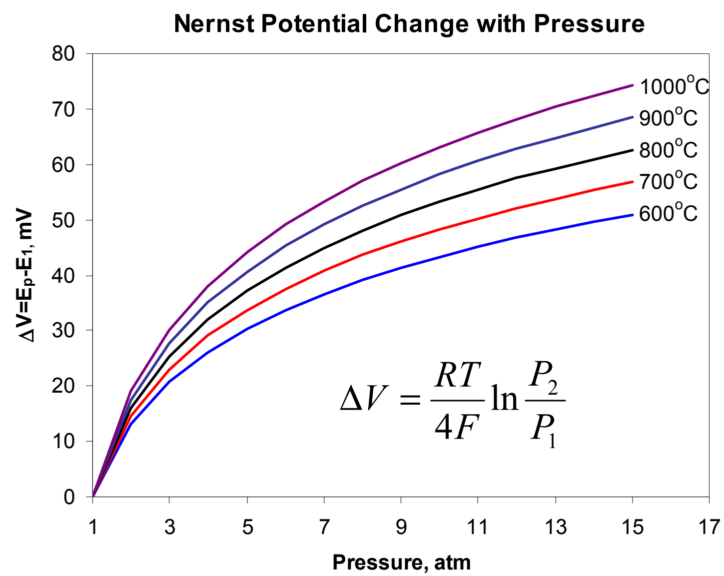
- **System trade studies**
- **Resolve technical barriers (high temp. HX, press. SOFC)**
- **Economic evaluation (market size, sensitivity of system economics)**

<u>Phase 2</u> (Q3/03 – Q3/04)

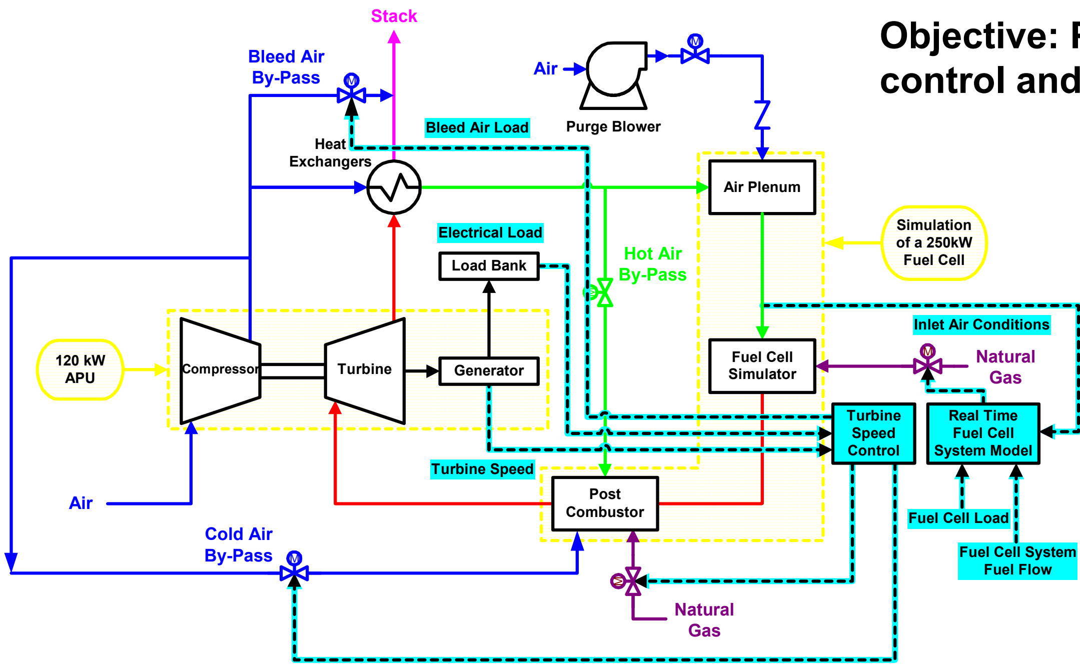
- **Detailed design of optimized system**
- **Detailed cost analysis of system**

<u>Phase 3</u> (Q/04 – Q4/05)

- **Operate a small integrated system of 15 kW stack, turbocharger, and heat exchangers**



NETL In-House Hybrid Performance Project



Objective: Provide a platform for assessing dynamic control and performance issues in FC/T hybrid systems

Technical Issues

- Identify dynamic interdependencies of FC/T hybrids
- Develop methods for managing thermal and load transients
- Minimize stress on FC & T in the hybrid system

Approach

- Simulation facility to examine dynamic conditions in a fuel cell gas turbine hybrid.
- Pressure vessels are used to simulate FC volume and time scales, and a combustor controlled by a real-time fuel cell model used to simulate thermal transients.
- Dynamic models provide experimental methodology.

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Hybrid Performance Project R&D Plan

- **Phase I - Speed Control and System Characterization**
  - Effective Speed Control During Startup and Load Change
  - Time Scales and Dynamics Characterized
  - Absorbing Thermal Transients
- **Phase II - Fuel Cell Simulation**
  - Integration of Alternative Real Time Fuel Cell Model
  - Turbine Speed Held Constant Through Variation of Load
  - Loss of Load to the Fuel Cell and Other Transients
  - Evaluation of Control Strategies
- **Phase III - Independent APU Speed Control and Load Following**
  - Secondary Combustion System for Independent APU Speed Control
  - Load Following Evaluation and Impact
  - Stall and Surge Dynamic Studies
- **Phase IV - Integration of a Commercial Fuel Cell**
  - Operability of the System During Transient Response
  - Testing of Control Strategies with Commercial SOFC
  - Auxiliary Firing for Spinning Reserve

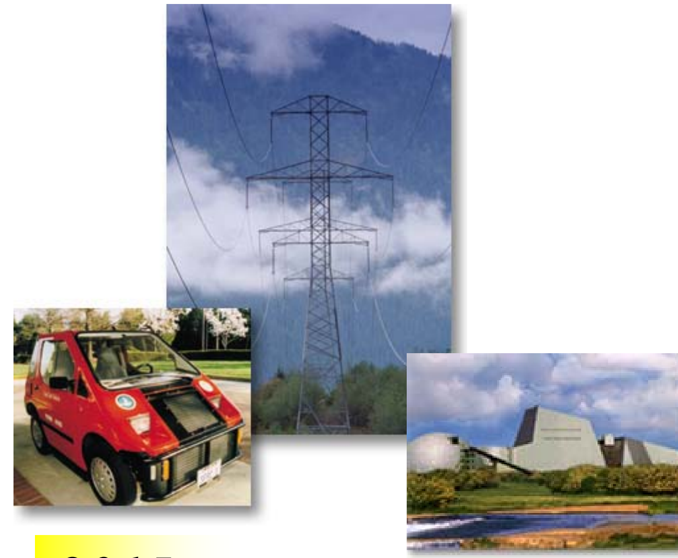
SECA Goals and Applications

2005

- **$800/kW**
  - Long-haul trucks
  - RVs
  - Military
  - Premium power

2010

- **$400/kW**
  - Residential & industrial CHP
  - Transportation auxiliary power



2015

- **Vision 21 power plants**
  - 75% efficient
- **Hybrid systems**
  - 60–70% efficient

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SECA

Six SECA Industry Teams

SIEMENS Westinghouse

DELPHI
Driving Tomorrow's Technology

Battelle

General Electric Company

Cummins Power Generation

SOFCo EFS Holdings, LLC
Solid Oxide Fuel Cells and Fuel Processors

FuelCell Energy, Inc.

Accu:metrics®

GENERAL DYNAMICS
C4 Systems

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Different Approaches!

Team	Design	Manufacturing
Cummins-SOFCo	• Electrolyte supported • 850 C • Thermally matched materials • Seal-less stack	• Tape casting • Screen printing • Co-sintering
Delphi-Battelle	• Anode supported • 750 C • Ultra compact • Rapid transient capability	• Tape casting • Screen printing • 2–stage sintering
General Electric Company	• Anode supported • 750 C • Hybrid compatible • Internal reforming	• Tape calendering • 2–stage sintering
Siemens Westinghouse	• Cathode supported • 800 C • Redesigned tubular • Seal-less stack	• Stack extrusion • Plasma spray

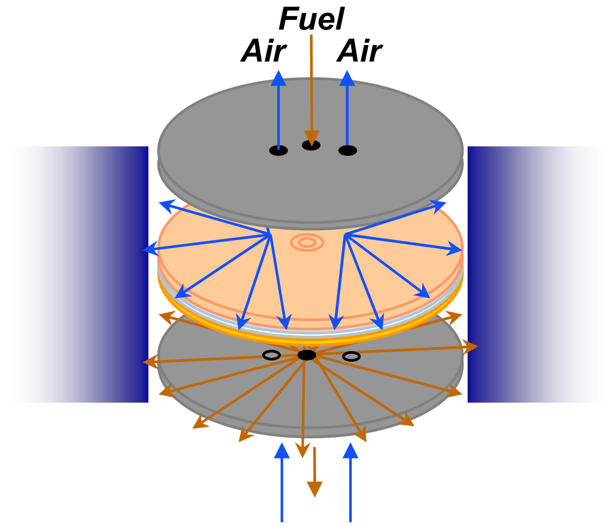
Two New Different Approaches!

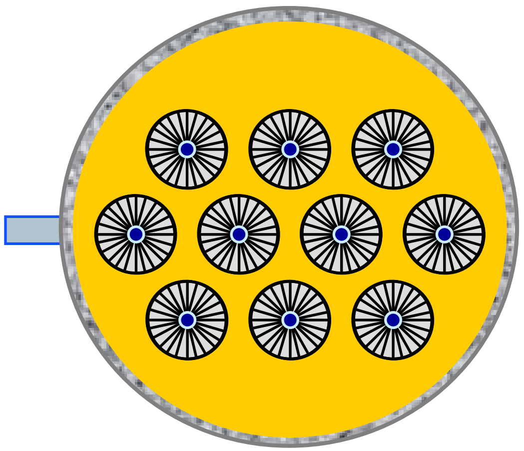
Team	Design	Manufacturing
Acumentrics Corporation	• Anode supported microtube • 750 C • Thermally matched materials • Robust rapid start-up	• Extrusion • Screen printing • Co-sintering
FuelCell Energy, Inc.	• Anode supported • < 700 C • Rapid transient capability	• Tape casting • Screen printing • Co-sintering • Electrostatic deposition

TIAX – Scale-Up of Planar SOFC for MW-Scale Systems

Objective: **Evaluate the integration of SECA planar stacks into MW-scale systems, including hybridization.**

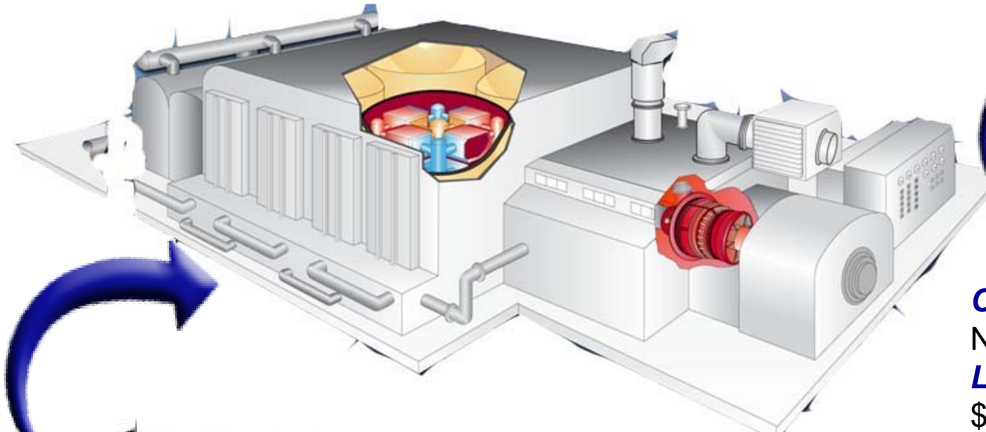
Approach: **TIAX developed SOFC model to estimate performance parameters for stack / system design and scale-up**



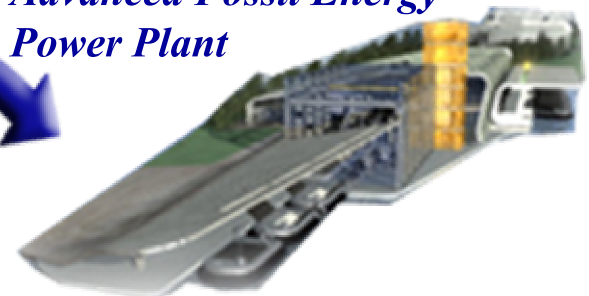


Fuel Cell Turbine Hybrids are Required for DOE's FE Advanced Power Plants

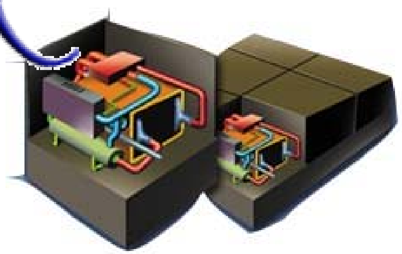
Hybrid System



Advanced Fossil Energy Power Plant



Clean
Near-zero Emissions
Low Cost
$400 per kilowatt
Flexible
Multiple fuel capacity
Energy Security
Rely on our vast domestic supply of coal



Solid Oxide Fuel Cells

Turbines

Office of Fossil Energy

Turbine Program

Gasification Technologies Program

Fuel Cell Program

SECA

NETL

Conclusions

- Fuel cell turbine hybrids are essential in order to meet DOE's goals for zero emissions, high efficiency, sequestration ready advanced fossil fueled power plants (coal and NG)
- DOE-FE goals are for large central station hybrids, however DG applicable power systems will evolve as a result of this R&D program
- Technical issues include: fuel cell cost reduction, FC with higher power densities, optimized turbines for DG applications, advanced turbine cycles, dynamic control / operation of hybrids, and hybrid system component needs
- DOE's FE R&D program is in place to address <u>many</u> of these technical issues